

Article

Acoustic and Life Cycle Assessment of Textile Sound-Absorbing Elements in Party Tents

Fernando A. Mendiguchia ^{1,*}, Alberto Quitana-Gallardo ^{1,*}, Vanesa Saez-Giunta ¹, Juan G. Secondo-Maglia ²,
Javier Bono-Cremades ³ and Ignacio Guillén-Guillamón ¹

¹ Center for Physics Technologies, Universitat Politècnica de València, Camino de Vera, s/n, 46022 Valencia, Spain; vcsaez@upv.es (V.S.-G.); iguillen@fis.upv.es (I.G.-G.)

² Institute for Heritage Restoration, Universitat Politècnica de València, Camino de Vera, s/n, 46022 Valencia, Spain; jgsecmag@upv.es

³ Department of Graphical Expression in Architecture, Universitat Politècnica de València, Camino de Vera, s/n, 46022 Valencia, Spain; javierbono@upv.es

* Correspondence: fermeno@upv.es (F.A.M.); alquigal@upv.es (A.Q.-G.)

Abstract

In the context of temporary urban environments such as festivals and construction sites, acoustic discomfort inside textile-based party tents remains a critical yet under-addressed issue. This study, developed in collaboration with industrial partners from the construction and textile sectors, aimed to design and assess lightweight, flexible sound-absorbing solutions capable of improving acoustic comfort while reducing environmental impact. A set of nine composite textile samples were fabricated using combinations of recycled and technical materials. Their acoustic behavior was characterized through standardized laboratory tests (ISO 10140-2 and ISO 354:2004) and full-scale prototypes under simulated real-world conditions. Simultaneously, a Life Cycle Assessment (LCA) was conducted according to ISO 14040:2006 and EN 15804:2020 standards to quantify environmental impacts from cradle to gate. The results demonstrate that it is possible to achieve an effective balance between acoustic performance and environmental sustainability. Integrating both types of assessment into the material selection process enables more informed, responsible design decisions for temporary textile structures, aligning construction practices with growing demands for functional and sustainable solutions.

Keywords: textile sound absorbers; ephemeral architecture; acoustic performance; life cycle assessment; sustainable materials



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1. Introduction

In the context of ephemeral festive environments, party tents represent fundamental spatial frameworks for prominent cultural events, as observed in Seville's 'Feria de Abril' and Valencia's 'Fallas'. This type of textile architecture, characterized by its lightness, quick installation, and spatial adaptability, has evolved from its origins in military tents and emergency structures into genuine temporary pavilions capable of hosting thousands of people [1]. However, despite their effectiveness in creating temporary event spaces, these tents usually fall short in terms of acoustic performance, both sound insulation and absorption. On the one hand, excessive sound reflection within these enclosures hampers communication, diminishes music intelligibility, and contributes to listener fatigue [2]. On the other hand, the limited sound insulation these textile enclosures provide con-

tributes to increased noise pollution, which can be extremely high in festivities such as the mentioned 'Fallas'.

The primary cause of these shortcomings lies in the most used materials: plastic tarpaulins made from PVC or coated polyester. While these ensure waterproofing and mechanical strength, they have low surface mass and limited porosity, resulting in poor sound absorption coefficients that increase reverberation [2,3].

The characterization of these materials relies on standardized methods, such as the impedance tube and reverberation chamber techniques, which enable the measurement of absorption coefficients, airflow resistance, and sound transmission loss [4–6]. Furthermore, studies on multilayer membranes and hybrid structures have revealed the influence of structural parameters, thickness, surface mass, porosity, and membrane tension on sound absorption efficiency [7,8]. In the specific context of tents and temporary shelters, controlled perforation and appropriate tensioning of the membrane have been shown to be key factors for improving both sound isolation and absorption [2].

Moreover, these petrochemical-based polymers require high energy inputs for their production and present recycling challenges at the end of their life cycle, significantly contributing to the environmental footprint of temporary architecture [9].

Faced with this environmental challenge, over the past few decades, the development of sustainable acoustic materials has consolidated as a key strategy to reduce both the environmental impact of construction and the health risks associated with traditional synthetic absorbers [10]. Several studies have shown that panels made from recycled fibers, such as paper, wool, or textile waste, can offer sound absorption coefficients comparable to those of conventional porous materials, with significant reductions in embodied energy, greenhouse-gas emissions, and production costs [10,11]. In parallel, recent reviews on natural fibers as absorbers indicate that many bio-based materials achieve acoustic performance comparable to glass or mineral wool but with a lower carbon footprint and a better sustainability profile, reinforcing the interest in integrating Life Cycle Assessment criteria into the design of acoustic solutions for buildings [12].

Building on this line of work, several studies have explored specific alternatives based on innovative textile materials, including even the use of woven structures [13]. The use of post-industrial cotton and polyester waste bound with natural rubber has enabled the production of acoustic panels with Noise Reduction Coefficients (NRC) ranging from 0.5 to 0.7, values comparable to those of commercial solutions [14]. Similarly, repurposed polyamide mask waste has shown notable acoustic performance in mid and high frequencies, with absorption capacity improving as thickness and density increase [15]. Other innovative approaches include chemical and physical fiber modifications, such as alkalization, plasma treatment, and the incorporation of micro- or nanofibers, to enhance sound energy dissipation without compromising flexibility [16]. Other studies include the use of waste-based composites, such as rice stubble powder [17].

The integration of life cycle assessment (LCA) methodologies allows for the quantification of environmental impacts associated with raw material extraction, manufacturing, transportation, and end-of-life management [9]. Recycled nonwoven polyester panels with NRC values above 0.2 have been analyzed and confirmed as viable, sustainable options in construction [18]. Similarly, technical products recycled from the automotive industry have reached NRC values up to 0.81, meeting ISO 11654 standards [3]. Linking acoustic performance to environmental impact has been studied by other researchers in the past. For example, Bader et al. linked sound and thermal insulation in CLT timber systems to demonstrate that optimal acoustic performance can be achieved with a moderate environmental footprint [19].

This research, developed through a collaboration between the Universitat Politècnica de València and a private-sector company, involved the design and characterization of flexible, lightweight sound-absorbing prototypes for use in party tents and other noisy environments. These samples, manufactured through the combination of recycled materials and technical fibers were evaluated in both laboratory conditions and simulated real-world scenarios, allowing the assessment of their acoustic performance through acoustic measurement techniques. Simultaneously, a cradle to gate Life Cycle Assessment was also conducted.

The objective of this study is to explore the possibility of improving the sound insulation of party tents and increasing their sound absorption, while simultaneously evaluating their environmental impacts. This enables us to assess the environmental trade-off between enhancing acoustic performance and increasing environmental burdens. Although integrated acoustic–environmental approaches have been reported for other construction materials, to the authors’ knowledge this combined assessment has not previously been applied to party tents or to lightweight temporary textile structures, whose specific material constraints, PVC or coated-polyester membranes, loose absorbing layers, and demountability, distinguish them from conventional building solutions.

2. Materials and Methods

The methodology applied in this research is structured around two fundamental pillars: the evaluation of the acoustic behavior of materials, sound insulation and absorption, and the analysis of their environmental impact through the life cycle assessment (LCA) methodology. This allows for an integrated assessment of both the functional effectiveness of the proposed solutions and their environmental burdens. The following subsections describe the different samples used, the acoustic testing and the LCA methodology.

2.1. Samples for Flexible Sound-Absorbing Solutions

In collaboration with manufacturers from the sector, a series of samples were developed, combining different textile solution options. The samples used for testing are depicted in Figure 1. The arrow represents the incident sound wave. In those cases in which the sample includes sound-absorbing materials, those materials are placed inside fabric bags. This option was used as the most optimal in terms of technical simplicity despite the discontinuity of the material.

The nine samples were selected and conceived as an incremental matrix that isolates the contribution of each constructive strategy. Sample S1, a single PVC fabric layer, represents the base case and the most widespread solution in the temporary-structure industry. From this baseline, the remaining samples introduce controlled variations so that, in most cases, consecutive samples differ in a single layer, allowing the acoustic and environmental effects to be attributed to specific design choices. Thus, S5 doubles the fabric layer to assess the effect of mass on sound insulation; S2 adds a melamine-resin absorbing foam to evaluate sound absorption; S4 and S6 combine both strategies, with S6 further incorporating a waterproof layer; S3 replaces the melamine foam with a double-thickness polyester foam to compare absorbing materials; and S7, S8, and S9 explore alternative finishing and absorbing layers.

Based on the given samples, a detailed inventory of the materials per square meter has been developed, as depicted in Table 1. This list of materials is used in the subsequent phases of the Life Cycle Assessment (LCA), presented further on in this paper.

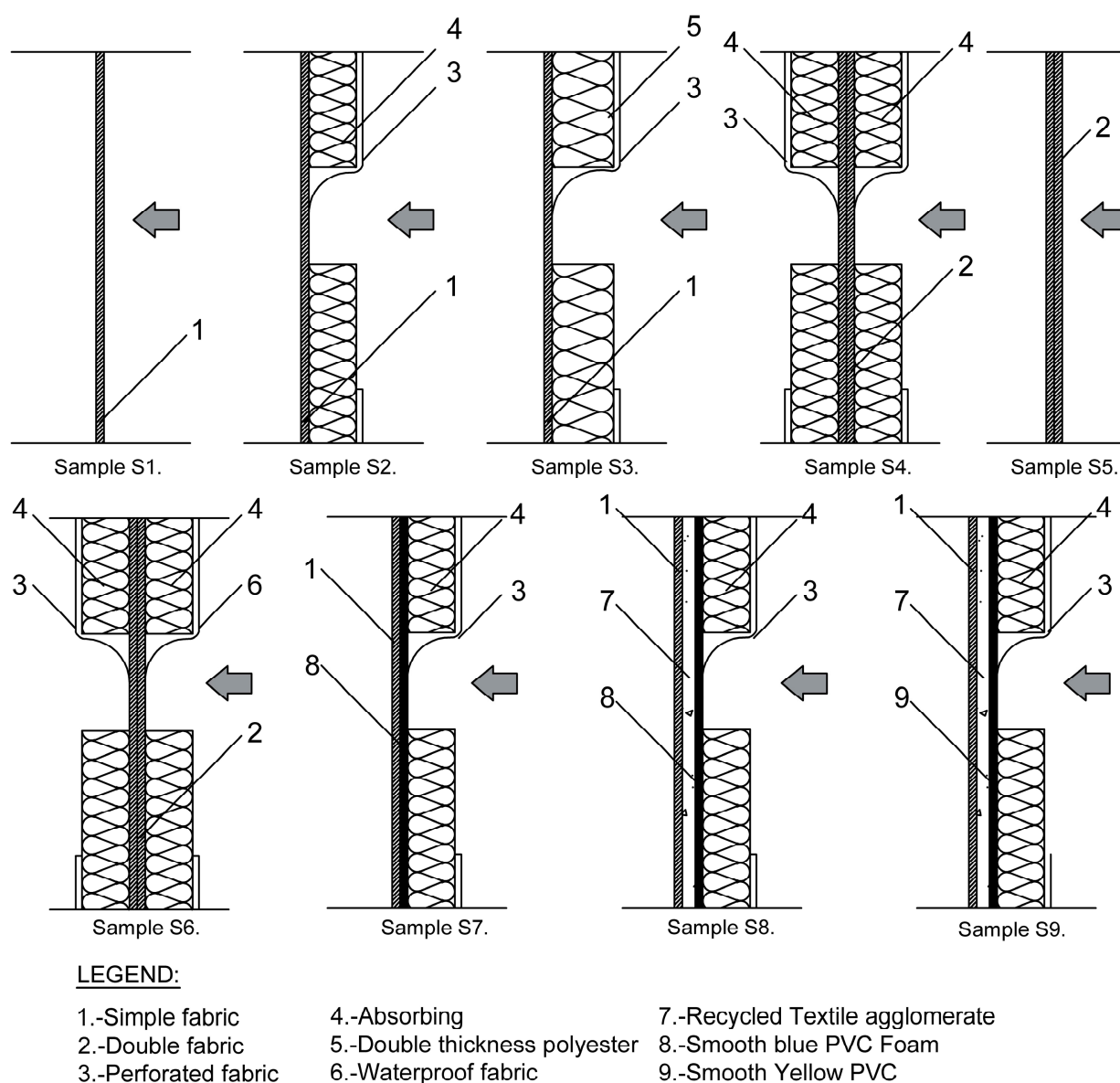


Figure 1. Samples used. Self-produced using Autodesk AutoCAD 2026 version.

In Table 1, the ID column identifies each constructive layer with a number, allowing the role of every layer to be traced across samples and cross-referenced with Figure 1. The layer types are: simple PVC fabric (1) and double PVC fabric (2), which provide the structural and mass-related insulating function; perforated PVC fabric (3), which acts as an acoustically transparent retaining layer for the absorbing core; melamine-resin foam (4) and double-thickness polyester foam (5), used as alternative sound-absorbing layers; waterproof PVC fabric (6), added for weather protection; recycled textile agglomerate (7), an alternative absorbing layer; and smooth blue PVC foam (8) and smooth yellow PVC sheet (9), used as finishing layers with differing acoustic and environmental behavior. For every layer, the thickness and density per square meter are reported; the totals per sample define the functional unit (1 m^2) subsequently used in the LCA. When a sample includes loose absorbing materials, these are housed inside fabric bags, which introduces a slight material discontinuity that is taken into account in the testing.

Table 1. Composition of the samples.

Samples	ID	Description	Material	Thickness (mm)	Density (kg/m ³)
S1	1	Simple fabric	PVC fabric	1.3	1.30
	Total			1.3	1.30
S2	1	Simple fabric	PVC fabric	1.3	1.30
	3	Perforated fabric	PVC fabric	1.0	0.32
	4	Absorbing material	Melamine resin foam	37	0.34
	Total			39.3	0.37
S3	1	Simple fabric	PVC fabric	1.3	1.30
	3	Perforated fabric	PVC fabric	1.0	0.32
	5	Double thickness polyester	Polyester foam	60	1.15
	Total			62.3	1.14
S4	2	Double fabric	PVC fabric	2.6	2.60
	3	Perforated fabric	PVC fabric	1.0	0.32
	4	Absorbing material	Melamine resin foam	37.0	0.34
	Total			40.6	0.48
S5	2	Double fabric	PVC fabric	2.6	2.60
	Total			2.6	2.60
S6	2	Double fabric	PVC fabric	2.6	2.60
	3	Perforated fabric	PVC fabric	1.0	0.32
	4	Absorbing material	Melamine resin foam	37.0	0.34
	6	Waterproof fabric	PVC fabric	1.0	0.32
	Total			41.6	0.48
S7	1	Simple fabric	PVC fabric	1.3	1.30
	3	Perforated fabric	PVC fabric	1.0	0.32
	4	Absorbing material	Melamine resin foam	37.0	0.34
	8	Smooth blue PVC foam	Foamed PVC	2.0	1.10
	Total			41.3	0.41
S8	1	Simple fabric	PVC fabric	1.3	1.30
	3	Perforated fabric	PVC fabric	1.0	0.32
	4	Absorbing material	Melamine resin foam	37.0	0.34
	7	Recycle Textile Agglomerate	Recycled textile	2.0	0.06
	8	Smooth blue PVC foam	Foamed PVC	2.0	1.10
	Total			43.3	0.39
S9	1	Simple fabric	PVC fabric	1.3	1.30
	3	Perforated fabric	PVC fabric	1.0	0.32
	4	Absorbing material	Melamine resin foam	37.0	0.34
	7	Recycle Textile Agglomerate	Recycled textile	2.0	0.06
	9	Smooth Yellow PVC	PCV sheet	2.0	1.10
	Total			43.3	0.39

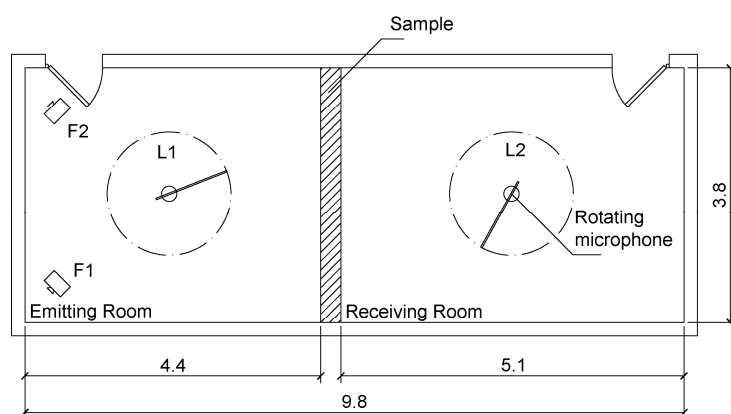
2.2. Acoustic Methods

The acoustic evaluation of the textile samples was structured into a three-phase hybrid methodology to ensure both standardized characterization and to try to replicate real-world applicability. First, laboratory testing of airborne sound insulation was conducted following the ISO 10140-2 [20] standard to determine the sound reduction index (R_w). Second, the diffuse sound absorption coefficient was measured in a reverberation chamber according

to UNE-EN ISO 354:2004 [21]. Third, prototype testing was performed, where the acoustic performance of a full-scale construction solution (a tent canopy and screen) was evaluated under controlled, yet simulated real-world conditions. This progressive approach allows for a comprehensive understanding of how the materials perform individually and when integrated into a temporary structural frame. To calibrate the equipment, we used the Hottinger Brüel & Kjær A/S (Virum, Denmark) calibrator model 4231.

2.2.1. Airborne Sound Insulation

To evaluate airborne sound insulation, a sound transmission chamber compliant with the ISO 10140-2 standard was used. The experimental setup consisted of a 12 m² sample installed as a dividing element between two acoustically isolated chambers, Figure 2b.



(a)



(b)

Figure 2. (a) Layout diagram of components in the transmission chamber; (b) Sample mounting in the test frame. Both images are self-produced: one created using Autodesk AutoCAD 2026 version (a) and the other taken inside the acoustic chamber at the receiving (b).

An omnidirectional sound source (B&K 4224) producing pink noise was placed in the emitting chamber, while rotating microphones (B&K 3923) in both chambers recorded the sound pressure levels L_1 and L_2 , where L_1 is the sound pressure level in the emitting room and L_2 is the sound pressure level in the receiving room. The sound reduction index (R_w) was calculated using the formula:

$$R_w = L_1 - L_2 + 10\log(S/A) \quad (1)$$

where S represents the sample area and A the equivalent absorption area in the receiving chamber (Figure 2).

2.2.2. Sound Absorption Measurement

The diffuse sound absorption coefficient was evaluated in a reverberation chamber according to UNE-EN ISO 354:2004. The chamber, with a volume of 217.73 m³ and surface area of 223.2 m², incorporated a diffuser system (27 hemispherical, 22 cylindrical, and 15 planar units) to ensure a diffuse sound field, as shown in Figure 3.

Testing involved measuring the reverberation time (T_{30}) with and without the sample, enabling calculation of the absorption coefficient (α) in one-third octave bands between 100 and 5000 Hz.

The resulting frequency-dependent absorption coefficients, derived directly from these comparative T_{30} measurements, were systematically recorded for each configuration.

These datasets were subsequently compiled to generate the spectral absorption curves, allowing for a clear, comparative visual analysis of how each additional material layer impacts the acoustic damping performance across the measured frequency spectrum.

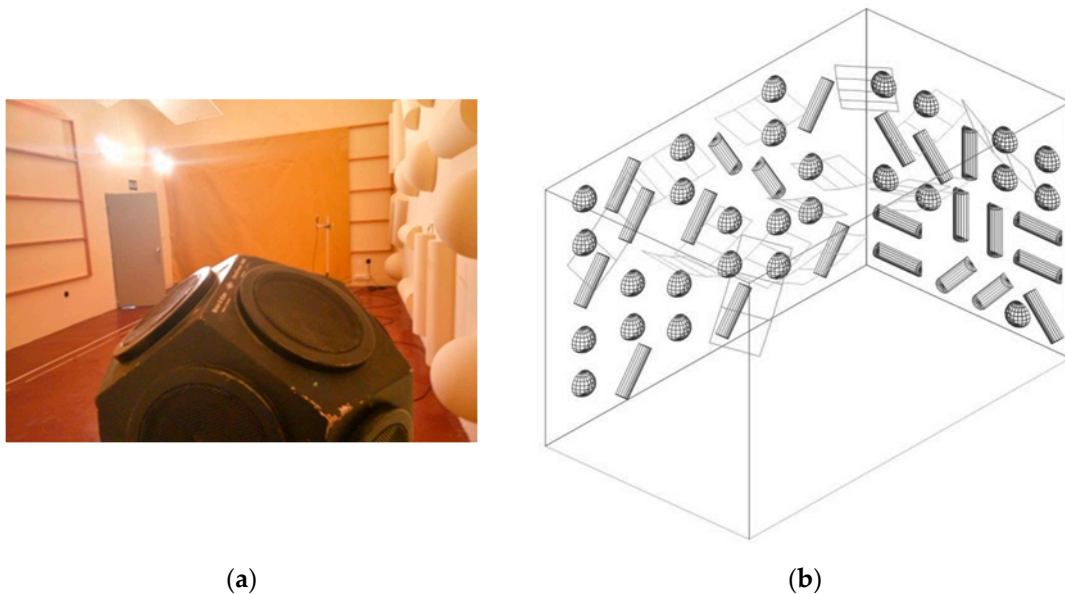


Figure 3. (a) Test setup configuration in the reverberation chamber; (b) Schematic diagram of the reverberation chamber used. Both images are self-produced: one taken inside the acoustic chamber (a) and the other created using Autodesk AutoCAD 2026 version (b).

2.2.3. Prototype Testing of Insulation Solutions

To validate acoustic performance under real-world conditions, a prototype was developed based on laboratory results. The prototype was configured by installing the selected sample (Sample 7) on a metal frame within a reverberation chamber located inside the Polytechnic University of Valencia facilities, as shown in Figure 4.

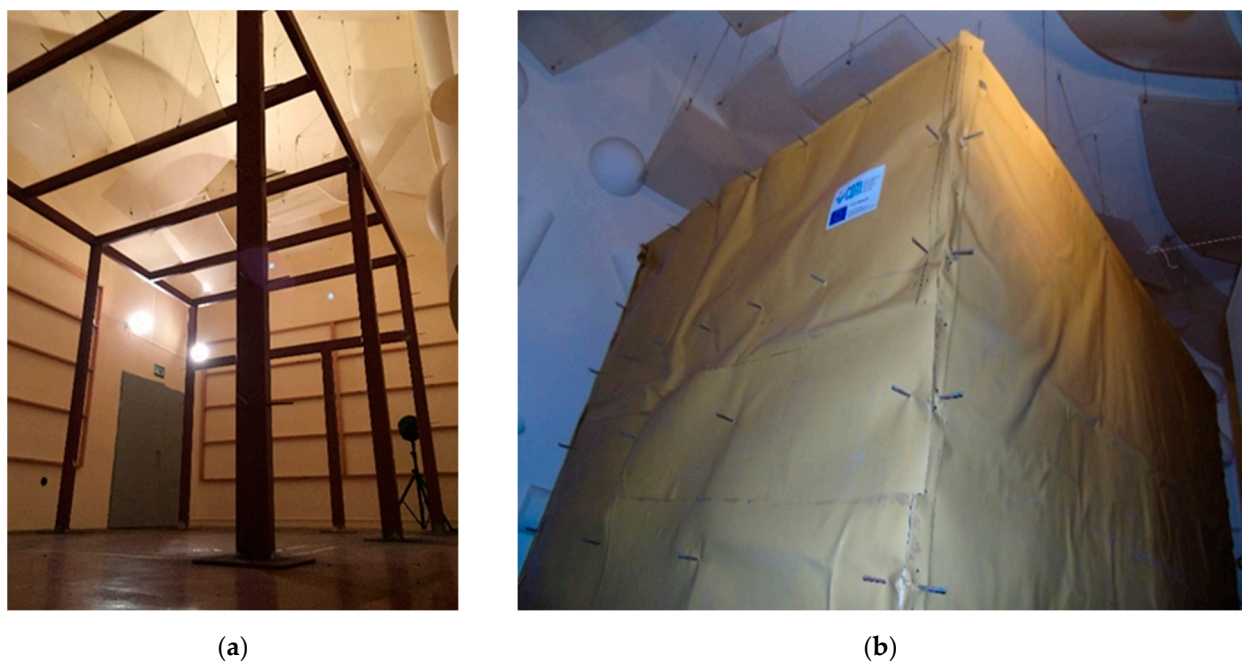


Figure 4. (a) Metal structure of the prototype in the reverberation chamber; (b) Prototype with sample installed. Both images are self-produced: taken inside the acoustic camera.

As depicted in Figures 5 and 6, the prototype consists of a tent, creating two spaces only separated by the sample. By placing a sound source inside the tent and measuring L1 (Sound Pressure Level inside the prototype), L2 (Sound Pressure Level outside the prototype), and B2 (Background noise outside the prototype), it is possible to assess the level difference between room 1 and 2 induced by the prototype.

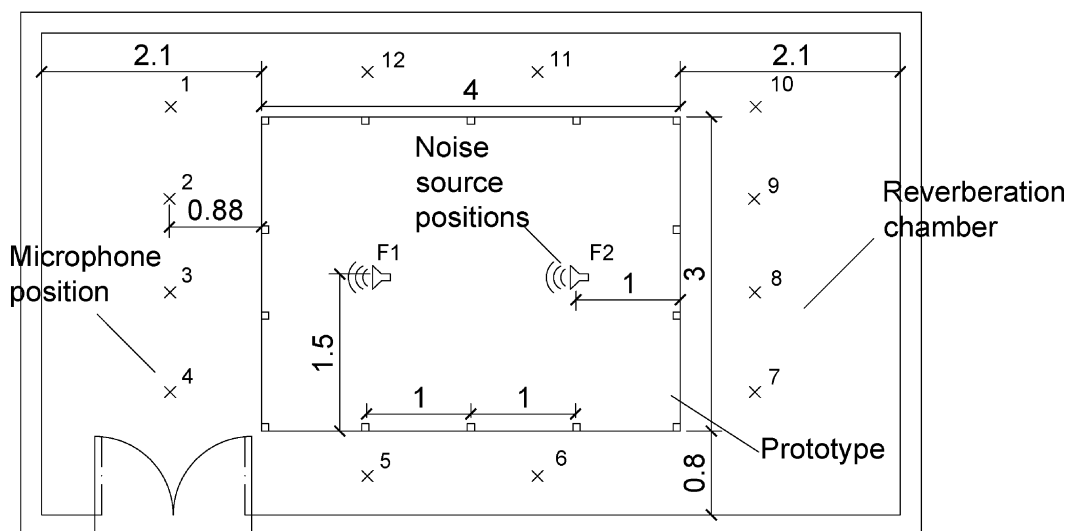


Figure 5. Plant diagram of the prototype testing procedure in the reverberation chamber. Numbers 1 to 12 refer to the different microphone positions. Self-produced using Autodesk AutoCAD 2026 version.

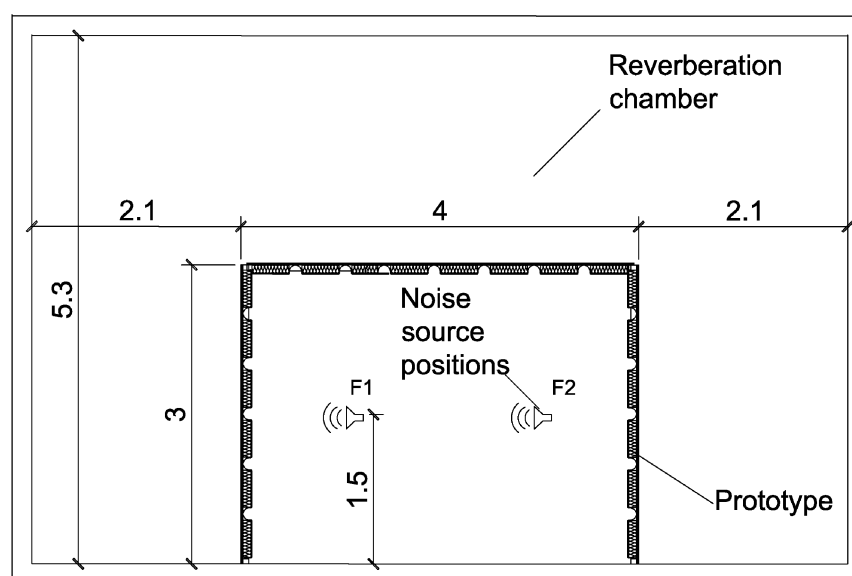


Figure 6. Section diagram of the prototype testing procedure in the reverberation chamber. Self-produced using Autodesk AutoCAD 2026 version.

2.3. Life Cycle Assessment Method

Life Cycle Assessment (LCA) is the most widespread method for environmental studies. The LCA in this study was performed according to the UNE EN ISO 14040:2006 [22] and EN 15804:2020 standards [23].

2.3.1. Goal and Scope

Among the LCA stages described in ISO 14040:2006, this study focuses on the A1 to A3 stages, which are the production of materials and the construction process phase. This

is due to the limited availability of reliable data regarding the actual end-of-life scenarios of the materials, which could introduce a high degree of uncertainty in the results. Moreover, the manufacturing process in these cases represents the most critical stage where it is especially important to analyze and compare the environmental impact of the samples.

2.3.2. Functional Unit

Defining the reference basis for comparison within an LCA study, the functional unit is an essential part of the process. Within this study, the most adequate functional unit is the square meter. This methodology was applied following [24,25].

2.3.3. Life Cycle Inventory

The Life Cycle Inventory (LCI) was developed using version 9.6 of the Simapro software, which integrates version 3.10 from the Ecoinvent database, one of the most comprehensive sources for LCA calculations [26]. The allocation method follows the end-of-life (EoL) allocation approach, as specified in EN 15804:2020 [23].

2.3.4. LCA Calculations

The LCA calculation was carried out using the Environmental Footprint methodology, v3. This methodology was developed by the Joint Research Center of the European Commission, more specifically by the European Platform of Life Cycle Assessment. Documentation of this methodology, as well as its normalization and weighting process, was developed by Zampori and Pant [27]. Based on the choice of evaluation method, the software proceeds to classify the output data obtained from the inventory and sorts them according to the impact category they affect. Furthermore, these classified values are simplified by characterization factors, resulting in what are called characterized results, according to each potential environmental impact category. Likewise, it should be noted that the evaluation method also presents the results through normalization and weighting. The values obtained for each impact category are multiplied by normalization factors to calculate and compare the magnitude of their contributions to the impact categories of the Environmental Footprint assessment method in relation to a reference unit. As a result, normalized and dimensionless values are obtained, which reflect the loads attributable to a product in relation to the reference unit. Within the method used, the normalization factors are expressed per capita based on a global value [28]. Weighting supports the interpretation and communication of analysis results. In this step, the normalized results are multiplied by a set of weighting factors (in %) that reflect the perceived relative importance of the life cycle impact categories considered [27].

3. Results

This section presents the acoustic and environmental results divided into several subsections.

3.1. Acoustic Performance

The results of the various tests conducted are presented below. This section is divided into two parts: the outcomes of the laboratory tests of the different samples and those from prototyping.

3.1.1. Airborne Insulation and Sound Absorption

Figure 7 and Table 2 present the laboratory results for the sound absorption and airborne sound insulation performance of the analyzed samples. While Figure 7 details the frequency-dependent diffuse sound absorption coefficients, Table 2 summarizes the overall acoustic behavior using single-number ratings. The weighted sound reduction

index (R_{wv}) was derived from the transmission chamber measurements (Equation (1)), and the weighted sound absorption coefficient (α_w) was calculated in accordance with ISO 11654. The meaning of Table 2 lies in its comparative structure: by quantifying the absolute increase in R_{wv} and α_w relative to the baseline configuration (Sample 1), it allows for a direct evaluation of how specific structural variations, such as the addition of melamine foam or double-fabric layers, impact the overall acoustic effectiveness of the temporary structure. L1 and L2 of each sample are reflected in Table 3.

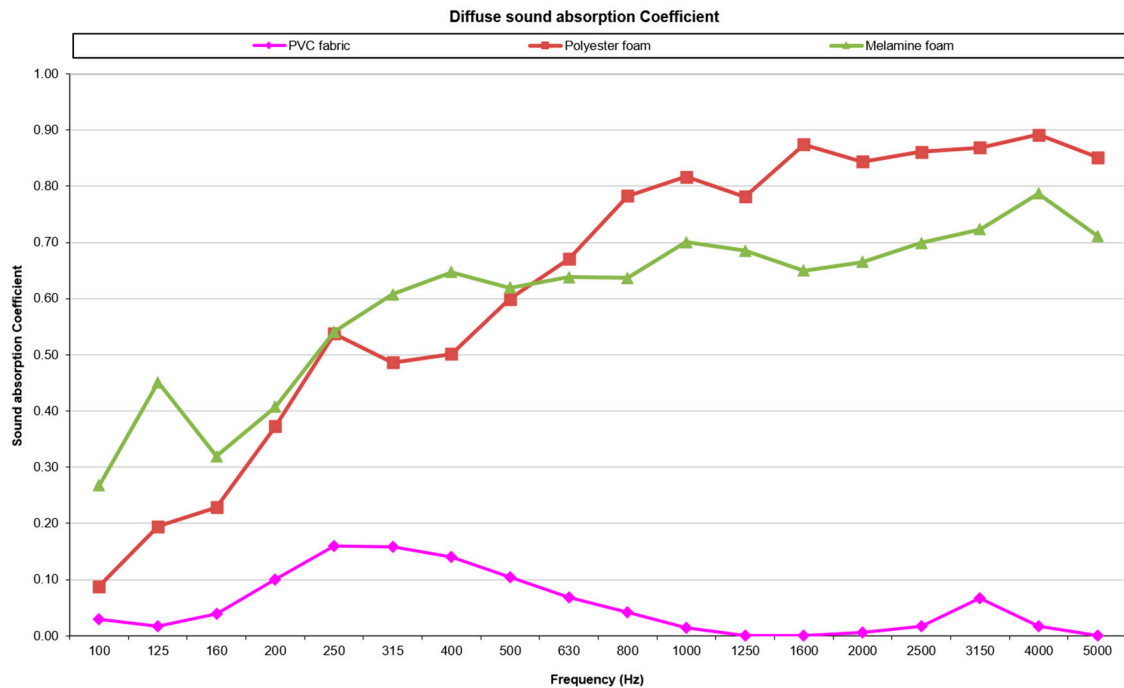


Figure 7. Diffuse sound absorption test results (ISO 354).

Table 2. Results obtained from airborne sound insulation and absorption of the samples.

Samples	R_{wv} (dB)	Increase Over Base R_{wv} (dB)	Weighted Sound Absorption Coefficient (α_w) ³	Increase Over Base Absorption
1 (base)	17	-	0.05	-
2	18	+1	0.65	+0.58
3	18	+1	0.65	+0.55
4	23 ¹	+6	0.65	+0.55
5	21 ²	+4	0.05	0
6	19	+2	0.65	+0.55
7	21 ²	+4	0.65	+0.55
8	19	+2	0.65	+0.55
9	19	+2	0.65	+0.55

¹ Best results. ² Second best result. ³ Calculation following the ISO 11654.

Specifically, Figure 7 shows the sound absorption coefficient obtained when the tent does not have any absorbent (samples 1 and 5) and when using absorbent 2 (sample 2), and when using absorbent 3 (samples 3, 4, 6, 7, 8, and 9). When looking at both the sound absorption and insulation results, samples 4 and 7 stand out by demonstrating a good balance between these two acoustic properties. They exhibit effective sound transmission reduction while maintaining a notable level of sound absorption.

Table 3. (a) L1 and L2 results of each sample (Part 1). (b) L1 and L2 results of each sample (Part 2).

(a)																	
Freq (Hz)	S1			L1 (dB)	S2		L1 (dB)	S3			L1 (dB)	S4			L1 (dB)	S5	
	L1 (dB)	L2 (dB)	R (dB)		L2 (dB)	R (dB)		L2 (dB)	R (dB)	L2 (dB)		R (dB)	L2 (dB)	R (dB)			
100	97.2	91	14.3	100.2	93.1	14.59	97.9	91.7	10.14	100.5	90.9	14.1	103.2	93.8	16.92		
125	99.7	93	13.79	101	95.2	11.75	98.6	93.8	8.312	100.4	94.5	10.07	103.9	97.2	13.53		
160	99.2	91.7	14.38	99.4	91	13.37	96	90	9.068	97.5	88.2	13.81	102	92.3	16.86		
200	97.9	92.5	13.28	97.6	92.1	10.23	97.6	91.5	9.751	98.7	90.6	12.92	102.6	94.9	14.87		
250	96.9	92.3	12.24	96.8	92.3	8.542	98.9	93.4	9.92	99.9	89.7	12.92	103.6	96.5	14.51		
315	94.3	89.7	11.97	97.8	91.9	9.729	99.6	92.6	11.42	100.7	88.3	13.65	104.5	96.4	14.46		
400	95.7	88.3	13.32	97.5	89.3	11.67	98.4	89.5	12.2	99.4	83.4	17.33	105	93.8	17.27		
500	97.6	89.4	13.16	97.8	87.5	12.69	100.8	90.2	12.93	101.5	81.8	19.57	105.9	93.7	17.32		
630	96.8	87.5	13.28	98.2	85.2	15.42	99.3	87	13.97	100.1	78	23.03	105.9	91.5	19.25		
800	95.7	85	13.72	96	80.8	17.71	98.6	84	16.51	98.8	74.7	25.27	104.3	88.7	19.9		
1000	93.3	81.7	15.34	92.8	76.3	19.13	95.3	79.9	17.54	95.4	71.2	25.04	101.1	84.6	20.54		
1250	90.5	77.5	16.25	88.8	70.6	20.71	92.1	74.8	19.99	91.6	66.8	25.68	97.7	79.9	22.14		
1600	91.4	75.9	19.17	87.8	69	21.82	91.8	73.5	21.26	90.6	66	25.69	98.3	78.7	23.74		
2000	90.7	73.9	20.34	87.7	67.7	23.04	91.2	71.3	22.92	90.7	64.5	27.61	97.2	76.3	25.13		
2500	85.7	67.7	21.09	82.5	61.9	23.4	86	65.3	23.58	85.5	59.6	26.74	92.2	70.5	25.37		
3150	82	63.8	20.94	79.8	60.6	21.47	83.2	63.3	22.01	82.7	58	25.58	88.9	67.7	24.4		
4000	77.8	59.2	20.81	74.7	56.5	20.38	78.3	58.8	21.38	77.9	54.9	23.03	84	63.5	22.95		
5000	72.2	51.5	22.26	70.2	49.9	22.07	73.5	52.7	22.54	73.3	48.9	24.27	78.8	56.8	24.11		
(b)																	
Freq (Hz)	S6			L1 (dB)	S7		L1 (dB)	S8			L1 (dB)	S9			L1 (dB)	R (dB)	
	L1 (dB)	L2 (dB)	R (dB)		L2 (dB)	R (dB)		L2 (dB)	R (dB)	L2 (dB)		R (dB)					
100	97.5	92.6	11.86	98.6	91.4	14.6	100.4	93.5	14.39	98.2	92.9	13.1					
125	99	95.8	7.007	100.1	93.6	12.38	102.1	97	11.83	100	95.5	9.9					
160	96.9	91.6	8.741	97.8	87.9	15.51	97.6	92.2	10.65	102.4	96.4	12.1					
200	94.4	90.1	8.129	94.1	85.3	14.34	99.5	93.4	10.92	97.9	92.3	12.0					
250	92.4	86.6	7.36	93	83.6	13.97	100.3	93.3	11.48	98.9	92.2	11.2					
315	95.3	85.9	10.92	96.3	85	15.19	100.3	91.5	12.84	97.8	90.2	11.6					
400	96.2	83.6	14.12	96.9	83.5	16.65	98.4	87.8	14.32	98.3	86.9	15.8					

Table 3. Cont.

(b)												
Freq (Hz)	L1 (dB)	S6 L2 (dB)	R (dB)	L1 (dB)	S7 L2 (dB)	R (dB)	L1 (dB)	S8 L2 (dB)	R (dB)	L1 (dB)	S9 L2 (dB)	R (dB)
500	95.5	79	18.02	96.8	80.4	19.2	100.6	86.5	16.84	99.8	85.3	18.3
630	95.9	75.6	21.93	96.4	78	20.91	99.5	83.7	18.95	98.5	82.2	18.7
800	93.7	74.3	21.17	94.8	75.9	20.88	98.1	81.3	19.19	97.3	80.2	19.5
1000	90.6	72.5	19.62	91.6	72.9	20.88	94.5	78.2	18.18	94.7	77.3	19.7
1250	87.1	68.1	21.21	88.1	68.3	21.94	91.1	73.8	19.44	90.6	72.8	19.9
1600	86.8	67.1	21.68	88.4	67.1	23.11	90.9	73.3	19.68	90.6	72.2	20.2
2000	86.7	66.1	22.61	87.3	65.2	24.15	90.3	71.4	20.53	89.8	69.8	21.9
2500	81	61.1	21.78	82.1	59.8	24.25	85.2	65.6	21.58	84.4	64.2	22.1
3150	78	61	18.49	79.4	58.2	22.83	81.7	63.9	19.47	81.3	62.7	20.2
4000	72.5	57	16.75	74.5	54.3	21.61	76.8	60.3	17.87	76.3	59.5	18.2
5000	67.8	50.8	17.88	69.6	48.6	21.84	71.7	54.1	18.44	71.3	53.2	18.8

3.1.2. Prototype Testing

Using the method described above, the difference in sound levels between the interior of the tent prototype and the exterior was measured, as shown in Figure 8, with sample 7. The total surface area of the prototype is 54 m². Note that this measurement method cannot be considered equivalent to determining an R_w value, as the necessary room volumes are not available and the setup presents uncontrolled flanking transmissions. L1, L2 and B2 are depicted in Figure 9. The purpose of this test was to evaluate the behavior of the material in semi-real-world conditions, similar to an outdoor tent installation, while still operating within a laboratory environment under controlled ambient conditions.

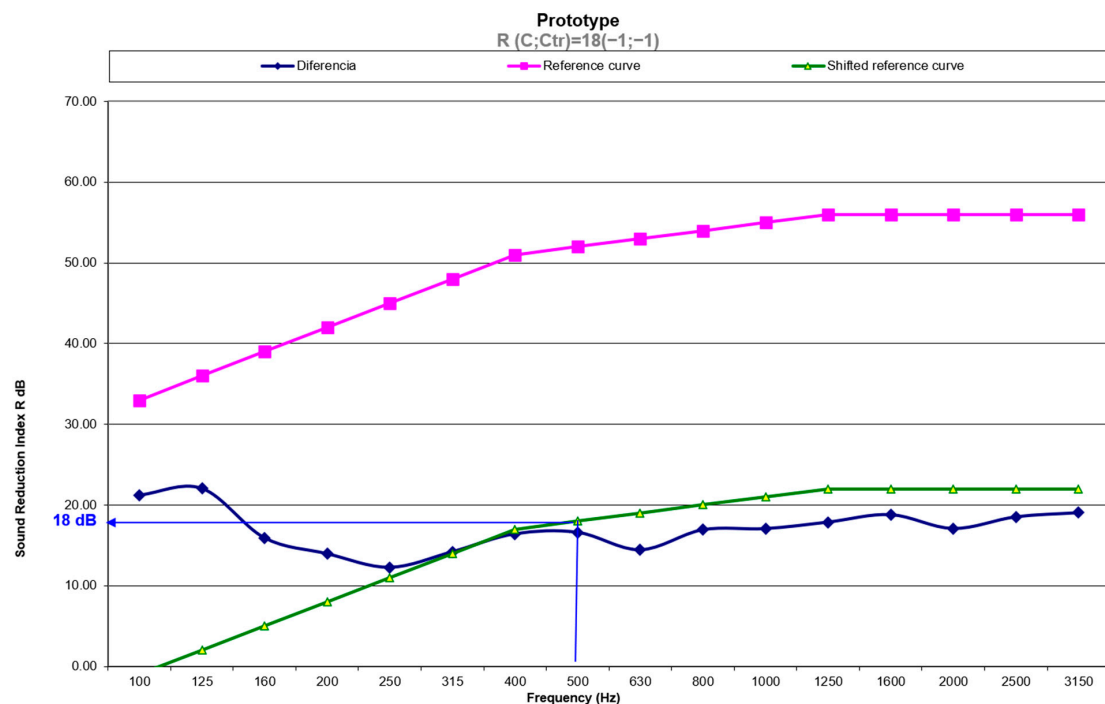


Figure 8. Prototype test result in reverberation chamber: difference sound level = 18 (−1; −1) dB.

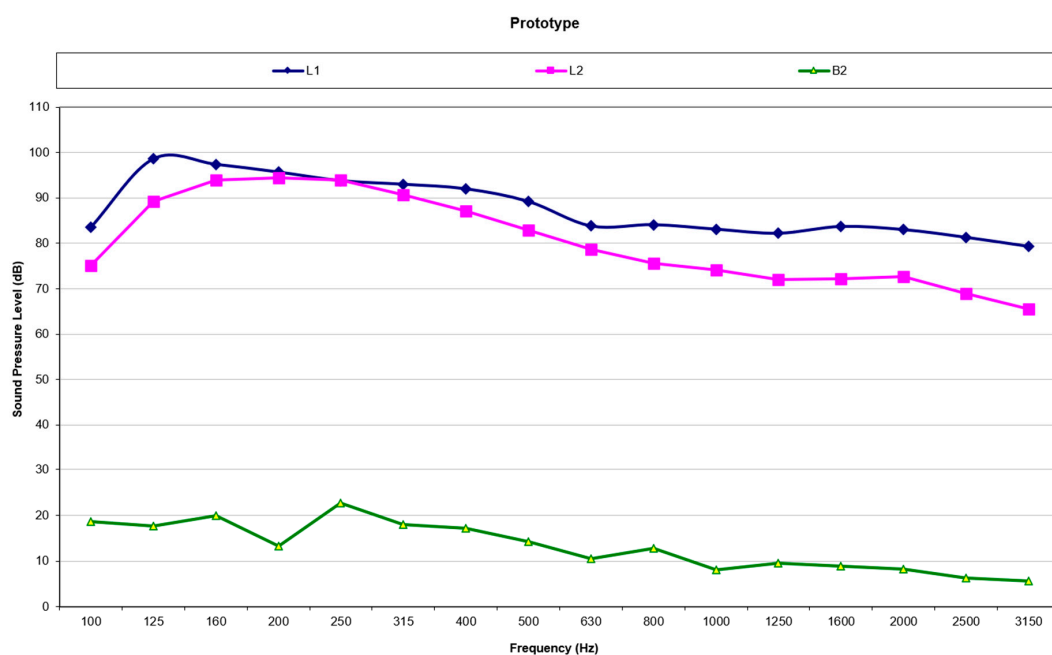


Figure 9. Measurement of L1 (Sound Pressure Level inside the prototype), L2 (Sound Pressure Level outside the prototype) and B2 (Background noise outside the prototype).

Figure 8 graphically illustrates the procedure used to derive a single-number rating for the prototype's acoustic performance. The blue curve represents the measured sound pressure level difference ($D = L1 - L2$) between the interior and exterior of the tent across the frequency spectrum. To evaluate this performance, the measured spectrum is compared against standardized reference curves (shown in pink and green), which are shifted in accordance with standard acoustic evaluation methods (ISO 717-1) [29] to determine the weighted value. The resulting value of 18 (−1; −1) dB indicates a weighted level difference of 18 dB at 500 Hz. The terms in parentheses are the spectrum adaptation terms: $C = -1$ dB for A-weighted pink noise and $C_{tr} = -1$ dB for A-weighted urban traffic noise. As noted earlier, this represents the prototype's behavior under simulated real-world conditions rather than a formal R_w value, as the tent structure inevitably presents uncontrolled flanking transmissions. Table 4 shows the L1 and L2 results of the prototype testing.

Table 4. L1 and L2 at each position.

Freq (Hz)	L1 (dB)		L2 (dB)			
	Pos 1	Pos 2	Pos 1	Pos 2	Pos 3	Pos 4
100	80.6	83.4	72.9	71.5	71.3	71.6
125	93.3	94.5	88.5	86.5	87.6	89.2
160	99.8	100.1	95	94	96.3	97.3
200	99.1	103.6	94.9	93.4	94.2	95.5
250	102.1	101.1	93.6	92.3	94.3	94.5
315	99.4	98.4	88.9	89.6	89.4	90.1
400	96.7	100.6	84.6	83.5	86.3	84.6
500	94.3	95.6	82.1	80.3	80.4	80.6
630	93.8	95.6	78.8	76.9	76.9	77.1
800	93	92.5	76	73.5	74.1	74.2
1000	92.4	93	74.6	73	75.1	71.8
1250	92.4	91.3	73.6	69.8	71.5	68
1600	94.2	93.4	73.3	70.9	73.3	69.5
2000	95.4	94.3	72.1	70.6	72.6	70.9
2500	92.8	92.1	70.1	67.8	69.6	67.4
3150	88.9	91.1	67	63.8	66.1	61.9
4000	89.2	86.6	63.8	62.2	62.8	59
5000	86.6	86.9	62.7	57.9	60	56.9

3.2. Life Cycle Assessment

The LCA study was conducted on the nine samples previously analyzed for their acoustic performance. The objective of this assessment is to quantify the environmental impact of the samples provided by the manufacturers and identify how improving the acoustic behavior changes the environmental impacts. Given this manufacturer-focused approach, the scope of the LCA covers stages A1 to A3, known as cradle to gate, which correspond to the processes under the manufacturer's responsibility. As mentioned above, the functional unit defined for the samples is one square meter (m^2), as this is the standard reference unit for this type of temporary textile structure. The following sections present the results obtained for this functional unit in terms of the single weighted score and the normalized and weighted results.

Tables 5 and 6 show the detailed LCA results divided into sixteen different impact categories. The most important differences can be observed in the climate change category, which shows that adding an absorbing layer increases the carbon dioxide emissions significantly. As it was expected, sample one is the least emitting one, which translates into 1.12 kg of CO_2 equivalent per square meter. Sample eight becomes the one with the highest

carbon emissions, with 7.55 kg of CO₂ equivalent. Sample seven, the one selected for the prototype, comes in second in terms of its carbon dioxide emissions, with 7.2215.

Table 5. Life cycle assessment characterization (Part 1).

Damage Category	Unit	S1	S2	S3	S4	S5
Acidification	mol H+ eq	0.0053	0.0122	0.0255	0.0176	0.0107
Climate change	kg CO ₂ eq	1.1263	2.7773	6.0499	3.9036	2.2526
Ecotoxicity, freshwater	CTUe	3.90	6.18	9.34	10.08	7.80
Particulate matter	disease inc.	5.70×10^{-8}	1.36×10^{-7}	2.91×10^{-7}	1.93×10^{-7}	1.14×10^{-7}
Eutrophication, marine	kg N eq	0.0011	0.0024	0.0046	0.0035	0.0023
Eutrophication, freshwater	kg P eq	0.0005	0.0008	0.0011	0.0013	0.0010
Eutrophication, terrestrial	mol N eq	0.0110	0.0238	0.0476	0.0348	0.0221
Human toxicity, cancer	CTUh	2.16×10^{-9}	3.50×10^{-9}	5.43×10^{-9}	5.66×10^{-9}	4.32×10^{-9}
Human toxicity, non-cancer	CTUh	7.15×10^{-9}	1.19×10^{-8}	1.89×10^{-8}	1.90×10^{-8}	1.43×10^{-8}
Ionizing radiation	kBq U-235 eq	0.1704	0.2454	0.3243	0.4158	0.3407
Land use	Pt	14.50	19.47	22.80	33.98	29.01
Ozone depletion	kg CFC11 eq	1.20×10^{-8}	2.99×10^{-8}	6.54×10^{-8}	4.19×10^{-8}	2.40×10^{-8}
Photochemical ozone formation	kg NMVOC eq	0.0037	0.0121	0.0301	0.0158	0.0074
Resource use, fossils	MJ	16.66	50.57	121.55	67.23	33.33
Resource use, minerals and metals	kg Sb eq	2.37×10^{-6}	3.51×10^{-6}	4.84×10^{-6}	5.88×10^{-6}	4.74×10^{-6}
Water use	m ³ depriv.	2.43	3.92	6.04	6.35	4.86

Table 6. Life cycle assessment characterization (Part 2).

Damage Category	Unit	S6	S7	S8	S9
Acidification	mol H+ eq	0.0189	0.0302	0.0322	0.0204
Climate change	kg CO ₂ eq	4.1808	7.2215	7.5538	4.4091
Ecotoxicity, freshwater	CTUe	11.04	10.47	11.93	12.14
Particulate matter	disease inc.	2.07×10^{-7}	3.46×10^{-7}	3.54×10^{-7}	2.10×10^{-7}
Eutrophication, marine	kg N eq	0.0038	0.0054	0.0057	0.0040
Eutrophication, freshwater	kg P eq	0.0014	0.0012	0.0015	0.0016
Eutrophication, terrestrial	mol N eq	0.0375	0.0561	0.0590	0.0394
Human toxicity, cancer	CTUh	6.19×10^{-9}	6.12×10^{-9}	7.00×10^{-9}	6.87×10^{-9}
Human toxicity, non-cancer	CTUh	2.08×10^{-8}	2.15×10^{-8}	2.70×10^{-8}	2.56×10^{-8}
Ionizing radiation	kBq U-235 eq	0.4577	0.3525	0.5507	0.6402
Land use	Pt	37.55	23.99	25.74	37.96
Ozone depletion	kg CFC11 eq	4.48×10^{-8}	7.81×10^{-8}	8.42×10^{-8}	4.98×10^{-8}
Photochemical ozone formation	kg NMVOC eq	0.0167	0.0365	0.0374	0.0173
Resource use, fossils	MJ	71.33	146.97	154.40	77.22
Resource use, minerals and metals	kg Sb eq	6.46×10^{-6}	5.31×10^{-6}	1.86×10^{-5}	1.95×10^{-5}
Water use	m ³ depriv.	6.95	6.80	6.89	6.82

3.2.1. Single Score

Due to the difficulty in analyzing characterization results, Figure 10 shows a single score result, which comes from the normalization and weighting of the characterization results. This allows for a simpler understanding of which samples are the most impactful when considering the most important impact categories.

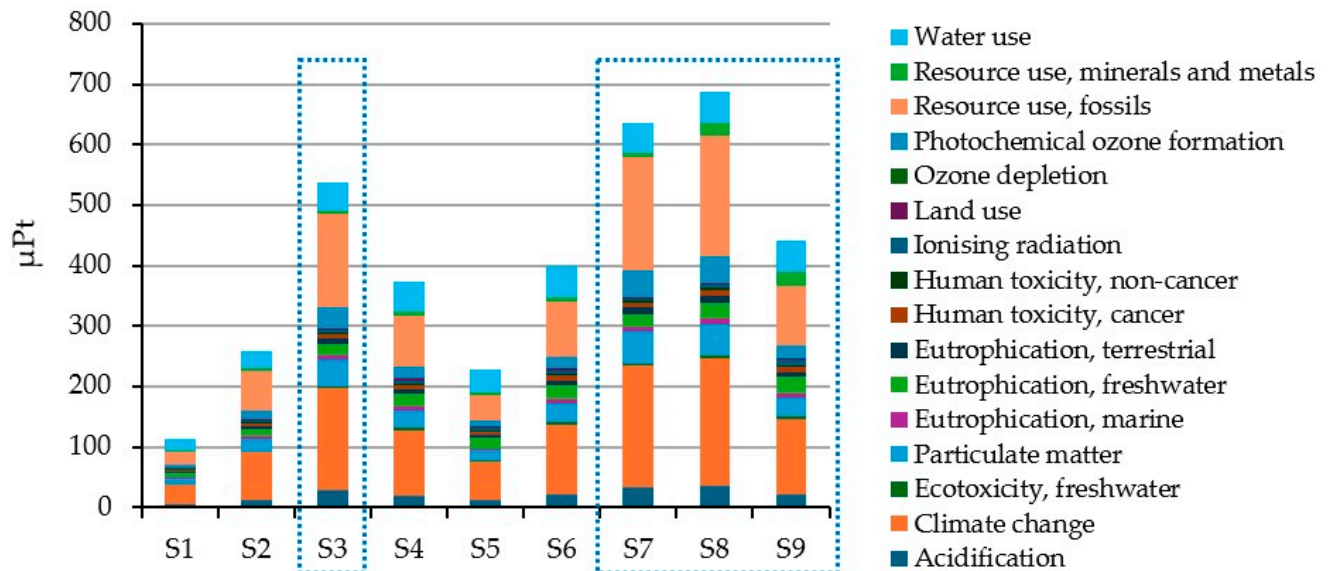


Figure 10. Comparing product stages; method: Environmental Footprint 3.1 (adapted) V1.01/EF 3.1 normalization and weighting set/single score/excluding infrastructure processes.

Focusing on an incremental order of the environmental footprint, the samples vary their impact depending mainly on the number of layers and their composition. Sample S1 presents the smallest score, with a total of 113.7 points, explained by being the one with a single fabric layer, conforming to the most used solution in the industry. Sample S5, which presents an additional layer of the same material, increases the impact by a factor of two, with a total of 227.5 points.

Sample S2, with a score of 258.4, and S4, with a score of 372.1, incorporate an additional absorbing foam layer composed of melamine resin, with the difference that S4 presents a double layer of fabric material, accounting for an increase of 113.7 points when compared to the first one. For sample S6, with a total of 400.1 points, the waterproof fabric supposes an additional impact of 28 points when compared to S4.

Among the samples with greater environmental footprint, samples S9, S3, S7, and S8—in incremental order of impact, respectively, account for the biggest amount of impact.

Sample S3, being the one with the lowest number of layers among the four, presents a considerable impact produced by the double-thickness polyester, accounting for almost 74% of its total impact.

Sample S7 presents two distinct materials from S3: the absorbing foam and smooth blue PVC foam, instead of the double-thickness polyester.

Among the samples with a large number of layers, it is worth noting that their material composition varies significantly in terms of their environmental footprint. Taking the four samples with the greatest environmental footprint, namely samples S3, S7, S8, and S9, their composition has a common base with some variations in their additional layers. For instance, samples S8 and S9 only differ in one layer, the PVC blue foam and PVC yellow sheet, respectively (see Figure 11). The 246.2-point difference may be explained by this material variation, with the PVC blue foam, with an impact of 377.4, responsible for a

greater impact than the PVC yellow sheet, with a total of 131.2 points. This last difference in material composition accounts for a 36% increase in the single score.

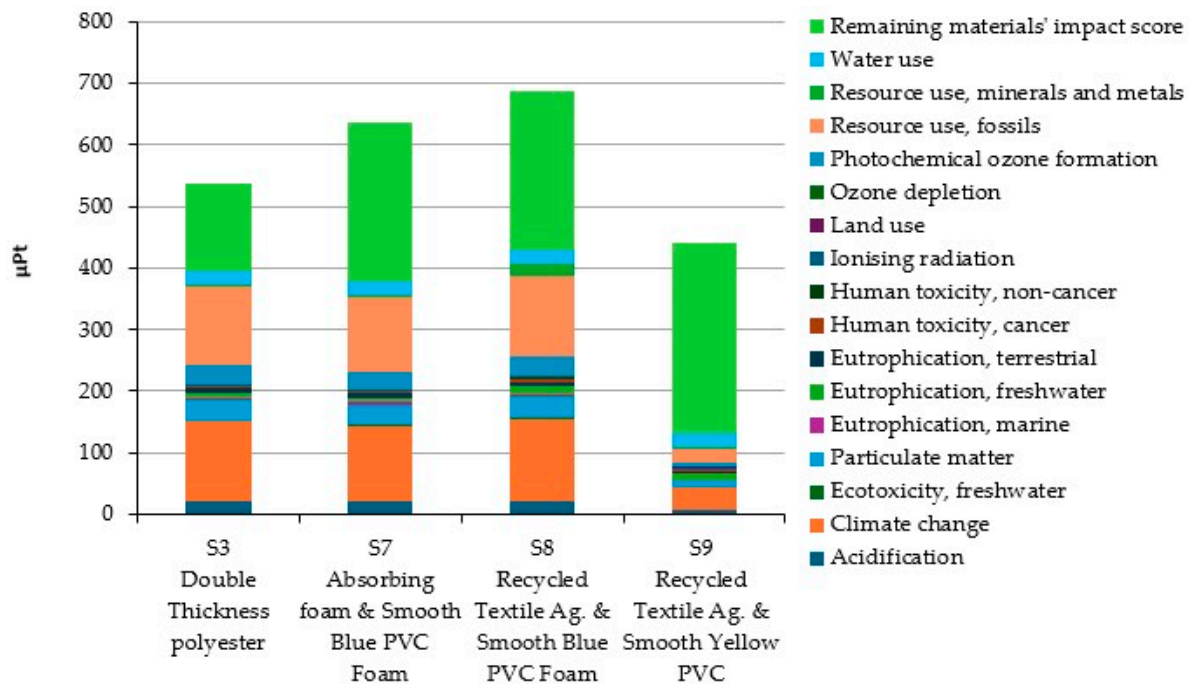


Figure 11. Comparing product stages; method: Environmental Footprint 3.1 (adapted) V1.01/EF 3.1 normalization and weighting set/single score/excluding infrastructure processes.

3.2.2. Normalized and Weighted Results

Figures 12 and 13 show the results for the nine samples for each of the sixteen impact categories, normalized and weighted according to the Environmental Footprint evaluation method. The impact domains with the highest impact observed are, in descending order, the use of fossil resources, freshwater eutrophication, climate change, and photochemical ozone formation.

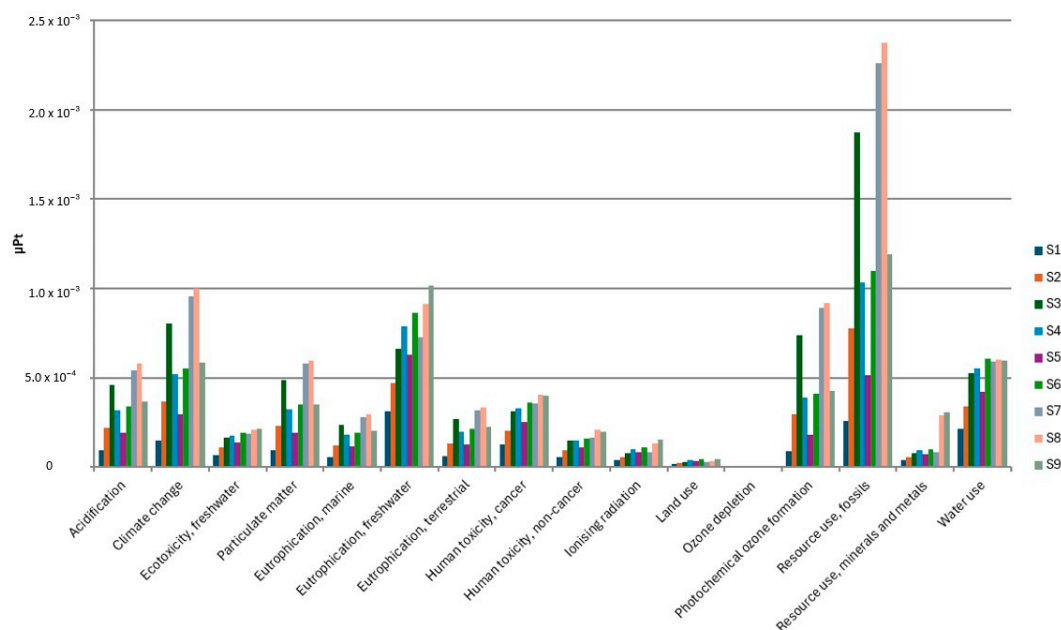


Figure 12. Comparing product stages; method: Environmental Footprint 3.1 (adapted) V1.01/EF 3.1 normalization and weighting set/normalization/excluding infrastructure processes.

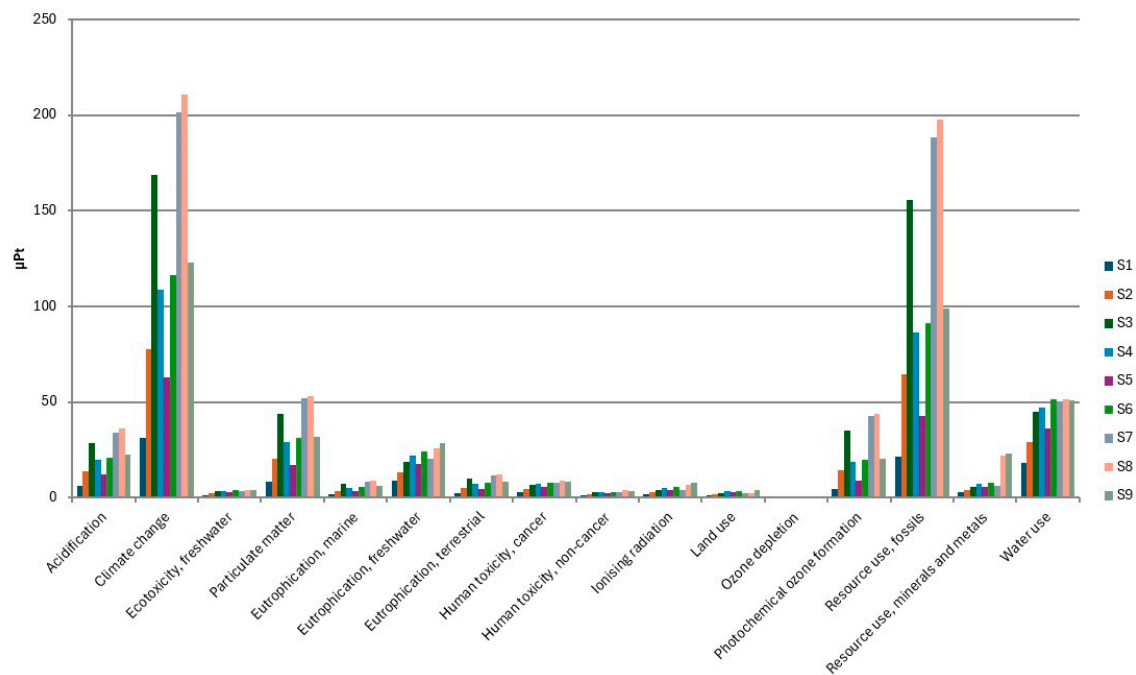


Figure 13. Comparing product stages; method: Environmental Footprint 3.1 (adapted) V1.01/EF 3.1 normalization and weighting set/weighting/excluding infrastructure processes.

Once the weighting is applied, and as depicted in the following graphic, this order changes, with climate change and fossil resource use being the impact domains with the biggest score, accounting for up to four times the additional score when compared with the rest. With a significantly lower score, water use and particulate matter emissions come as the third and fourth most important impacts when considering their contribution to the global impact.

4. Discussion

The results show tangible differences between samples, both in the acoustic properties and the environmental impacts. To better understand the results, this section develops a comparison of all the results with each other.

In terms of sound absorption, samples without the addition of foam showed an absorption coefficient of 0.05, namely samples 1 and 5. When adding foam, we are presented with two possible solutions depending on the material used. Those samples backed with polyester foam have a coefficient of 0.63. That is the case of only sample 3. The rest of the samples are backed with a layer of melamine foam, which results in an absorption coefficient of 0.60.

When trying to improve the indoor acoustic comfort of the tent, all the samples that include a foam absorbent will have a significant effect in reducing the reverberation time with respect to the base case.

The results show important differences when it comes to the airborne sound insulation. Considering that the base case achieves an R_{w} of 17 dB, it is possible to add up to 6 dB by adding a double layer of PVC fabric and melamine foam.

One of the main objectives of the study is to analyze the correlation between the acoustic and the environmental behavior of the analyzed samples. To evaluate this, a two-dimensional scatter plot is presented, where the vertical axis (Y) represents the sound reduction index (R_{w}) (in decibels) and the horizontal axis (X) corresponds to the environmental impact points, derived from the LCA presented in the previous section (Figure 13). Sound reduction levels ranged from 17 to 23, whereas the environmental values ranged

from 100 to 700; both have been evaluated under a monotonic interpretation whereby a higher sound reduction index indicates better performance and higher environmental impact indicates worse performance. To make both metrics comparable, the results were normalized using min–max scaling to [0,1] [0,1]. Sound insulation was linearly scaled from [17,23] to [0,1], while the environmental impact was scaled from [100,700] to [1,0] through scale inversion, so that 100 represents the optimum and 700 the worst case. A composite score in [0,1] was then defined as the arithmetic mean of the two normalized variables.

$$S_i = 1/2 \left(\frac{R_{w,i} - 17}{6} + \frac{700 - \mu Pt_i}{600} \right)$$

Table 5 presents, for each sample, the original values of the weighted sound reduction index $R_{w,i}$ and the environmental impact (μPt), together with their corresponding dimensionless values. The normalized columns place both variables on a common basis for comparison, while the final column (score) summarizes the overall performance of each solution. This score constitutes a quantitative performance-to-impact indicator: rather than a direct $R_{w,i}/\mu Pt$ ratio, which would not be physically meaningful, since $R_{w,i}$ is expressed on a logarithmic decibel scale and within a narrow range (17–23 dB), both variables are first brought to a common dimensionless [0,1] basis and then aggregated, so that higher score values denote a better acoustic–environmental trade-off. The indicator thus provides an objective, single-number criterion for the comparative ranking of the samples and the identification of the optimal solution. Table 7 presents the acoustic and environmental values of each sample jointly, together with an aggregated indicator of their performance.

Table 7. Sound insulation and environmental footprint evaluation results.

Samples	$R_{w,i}$	Normalized $R_{w,i}$ [0 to 1]	μPt	Normalized μPt [0 to 1]	Score (Composite Performance-Impact Index)
1 (base)	17	0	114 ¹	0.977	0.488
2	18	0.167	258	0.737	0.452
3	18	0.167	536	0.273	0.220
4	23 ¹	1	372	0.547	0.773 ¹
5	21 ²	0.667	227 ²	0.788	0.728 ²
6	19	0.334	400	0.500	0.417
7	21 ²	0.667	636	0.107	0.387
8	19	0.334	687	0.022	0.178
9	19	0.334	440	0.433	0.383

¹ Best results. ² Second best result.

According to the composite score, the samples can be ranked quantitatively as follows: S4 (0.773) > S5 (0.728) > S1/base (0.488) > S2 (0.452) > S6 (0.417) > S7 (0.387) > S9 (0.383) > S3 (0.220) > S8 (0.178). This ordering confirms, on a strictly quantitative basis, that S4 offers the best balance between sound insulation and environmental impact, followed closely by S5. It also shows that, although S7 reaches the same $R_{w,i}$ as S5 (21 dB), its markedly higher environmental footprint (636 vs. 227 μPt) drops it to the lower half of the ranking, a contrast that would not be apparent from the acoustic results alone.

Based on the normalized scores in Figure 14, each point is represented as a bubble whose size and color encode the sample quality: higher-performing samples with higher sound insulation and lower environmental footprint appear as large green bubbles, while lower-performing samples with lower sound insulation and higher environmental footprint are shown as small red bubbles.

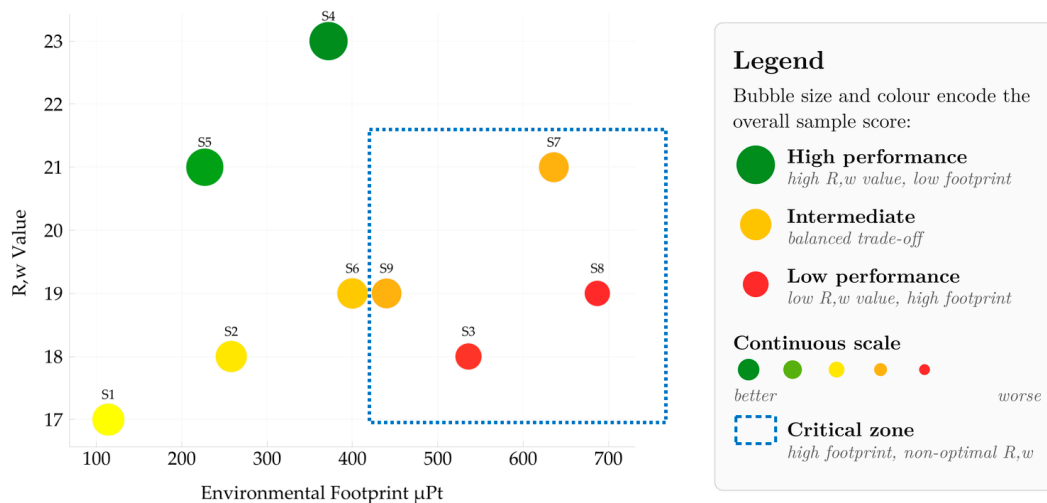


Figure 14. Sound insulation and environmental footprint evaluation.

This statistical representation allows simultaneous visualization of the positive and inverse relationships between acoustic and environmental parameters, making it possible for the decision-maker to address both variables when deciding which solution will be implemented.

The analysis carried out reveals that sample S4 represents the most balanced solution, as it combines high acoustic performance with moderate environmental impact, positioning itself as the most optimal option among the evaluated set. It is followed by sample S5, which, although it presents a slight reduction in its acoustic properties (2 dB less R_{w} than S4), compensates for this loss with a considerably lower environmental footprint. S5 exhibits sound insulation comparable to that of S7, but with an environmental impact three times lower, which reinforces its appeal as a sustainable solution.

On the other hand, samples S1 and S2, although exhibiting low environmental impact, do not reach acceptable levels of acoustic performance, which limits their applicability in contexts where sound comfort is a priority. Samples S3, S6, S8, and S9 show similar values in terms of sound insulation (between 18 and 19 dB R_{w}), but with notable differences in their environmental impacts, with the contrast between S6 and S8 being particularly noteworthy.

Overall, it can be considered that the use of these solutions can be adequate for real use cases such as music events or festivities. On the one hand, the sound insulation achieved by these tents is not comparable to that obtained with typical building constructions. Any brick or plasterboard wall would achieve values of over 30 dB. However, it can reduce the noise level of loud festivities to acceptable levels. In the case of the comfort inside the party tent, according to the results, adding sound absorbent can be extremely helpful for controlling the reverberation time.

Also, although this study has focused on the relationship between acoustic performance and environmental footprint, the final selection of a construction solution also depends on other relevant factors such as cost, ease of installation, and material availability according to the geographical context. In this sense, more comprehensive composite indicators could be developed in the future, integrating these economic and logistical variables alongside the acoustic and environmental ones considered here. Such indicators fall outside the scope of the present work, which deliberately concentrates on the acoustic–environmental trade-off; nevertheless, the normalized indices and composite scores presented here provide an objective basis that could be extended in subsequent studies to guide more sustainable and cost-effective decisions in the selection of construction solutions with good acoustic performance.

Furthermore, while this study has primarily focused on the relationship between acoustic performance and environmental footprint, the real-world adoption of these solutions heavily depends on practical considerations such as cost, durability, installation complexity, and long-term outdoor performance. Introducing acoustic layers, such as melamine or polyester foams (e.g., Samples 4 and 7), inevitably increases the overall weight and thickness of the textile structures. This added bulk can complicate the logistics of transport, folding, and the tensioning processes required during installation, practical limitations that directly influenced our decision to select the lighter Sample 7 over the acoustically superior Sample 4 for the full-scale prototype. Furthermore, in outdoor festive environments, these materials are exposed to demanding weather conditions, including UV radiation, moisture, and wind. Consequently, porous absorbing cores must be adequately protected by waterproof and UV-resistant outer layers (such as the configuration tested in Sample 6) to prevent moisture accumulation, rapid degradation, and the subsequent loss of long-term acoustic efficacy. Although alternative and recycled acoustic materials may currently present higher initial costs or distinct maintenance requirements compared to the standard, highly industrialized PVC tarpaulins, these must be evaluated holistically. Future research should aim to develop comprehensive composite indicators that integrate these techno-economic and durability variables alongside acoustic and environmental metrics, thereby guiding the temporary architecture industry toward solutions that are not only sustainable and quiet, but physically robust and economically viable.

Finally, it is important to acknowledge the limitations inherent in the chosen cradle-to-gate (A1–A3) system boundary for the Life Cycle Assessment. By excluding the use and end-of-life (EoL) stages, the current evaluation does not capture the environmental burdens or benefits associated with the disposal, recycling, or reuse of these materials. This omission has critical implications for temporary textile architecture, which inherently experiences shorter functional lifespans and higher turnover rates. For instance, traditional PVC membranes (Sample 1) pose well-documented recycling challenges and often result in landfilling or incineration, which can generate harmful emissions. In contrast, incorporating alternative materials like recycled textile agglomerates or polyester foams, while demonstrating a higher initial manufacturing impact (A1–A3) in our results, might offer superior recyclability or circular economy benefits at the end of their useful life. Consequently, the environmental penalty observed when adding acoustic layers could potentially be mitigated if those specific materials are integrated into closed-loop recycling systems. Future research should expand the LCA boundaries to a full ‘cradle-to-grave’ or ‘cradle-to-cradle’ approach to capture these critical EoL dynamics and provide a more definitive sustainability ranking.

5. Conclusions

Through the study of the materials used and the various tests conducted during both phases of the project, the following conclusions can be drawn:

- It is possible to combine different textile layers to improve the airborne sound insulation and the absorption of party tents.
- By adding melamine foam or polyester foam, the average absorption coefficient increases from 0.05 up to 0.63, which would lead to an improvement of the acoustic comfort inside the party tents.
- The airborne sound insulation results from the samples range from a sound reduction index of 18 dB (sample 1), in the base case, up to 23 dB when adding a double textile layer and a polyester foam backing (sample 4).

- Sample 7, which has a sound reduction index of 21 dB, is used to build the full-scale prototype because of the simplicity in the mounting process due to the lower weight with respect to sample 4.
- The tent prototype studied achieves a sound pressure interior-to-exterior level difference of 18 dB.
- The difference between sample 7 and the prototype is assumed to be due to the difficulty in patching in the corners of the prototype.
- It is essential to incorporate the Life Cycle Assessment (LCA) methodology into the evaluation of construction materials, especially for sound-absorbing materials, whose environmental impact has historically been underestimated. Understanding these impacts allows for more informed and responsible decision-making.
- Increasing the acoustic performance of party tents by adding absorbing layers and other additional materials implies significantly increasing the environmental impacts. The carbon emissions increase from 1.12 to 7.22 kg CO₂ eq when comparing sample 1 to sample 7.
- The most conventional materials in the industry continue to show a strong dependence on fossil resources, which translates into higher environmental impacts, particularly in the climate change category. These two categories are the most significant in almost all the scenarios evaluated, highlighting the urgent need to seek alternatives with a lower environmental footprint.
- The intersection of acoustic and environmental data emerges as a key tool in the material selection process. An acoustically efficient solution is not always the most sustainable, and vice versa. This integrated approach can significantly influence design and technical specification decisions.
- Beyond the specific case of party tents, this study establishes a replicable methodological framework that integrates acoustic testing with life cycle assessment, enabling designers and researchers to systematically compare lightweight envelope solutions in other forms of temporary architecture such as pavilions, emergency shelters, exhibition structures, and mobile installations.
- Although other factors such as cost, ease of installation, or local availability also influence the final choice of material, the present study demonstrates that it is possible to achieve a better balance between acoustic performance and environmental sustainability, promoting more conscious decisions aligned with the current challenges facing the construction sector.

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